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A STUDY OF COMPOSITE PLATES WITH HOLES/INCLUSIONS

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MODEL DESCRIPTION

Delamination characterization of a plate with a hole/inclusion is presented. A closed form solution is developed to obtain stresses on the boundary of hole/inclusion in the plate. Once the location with highest tangential stress is identified, FEM analysis of a laminate under tensile loading is considered. The models for the closed form and FEM are given in Figure 1 A & B. The examples are for $[\pm 35/0/90]_s$ laminate of AS4/3501-6. Tensile, Biaxial and Shear loads are considered.

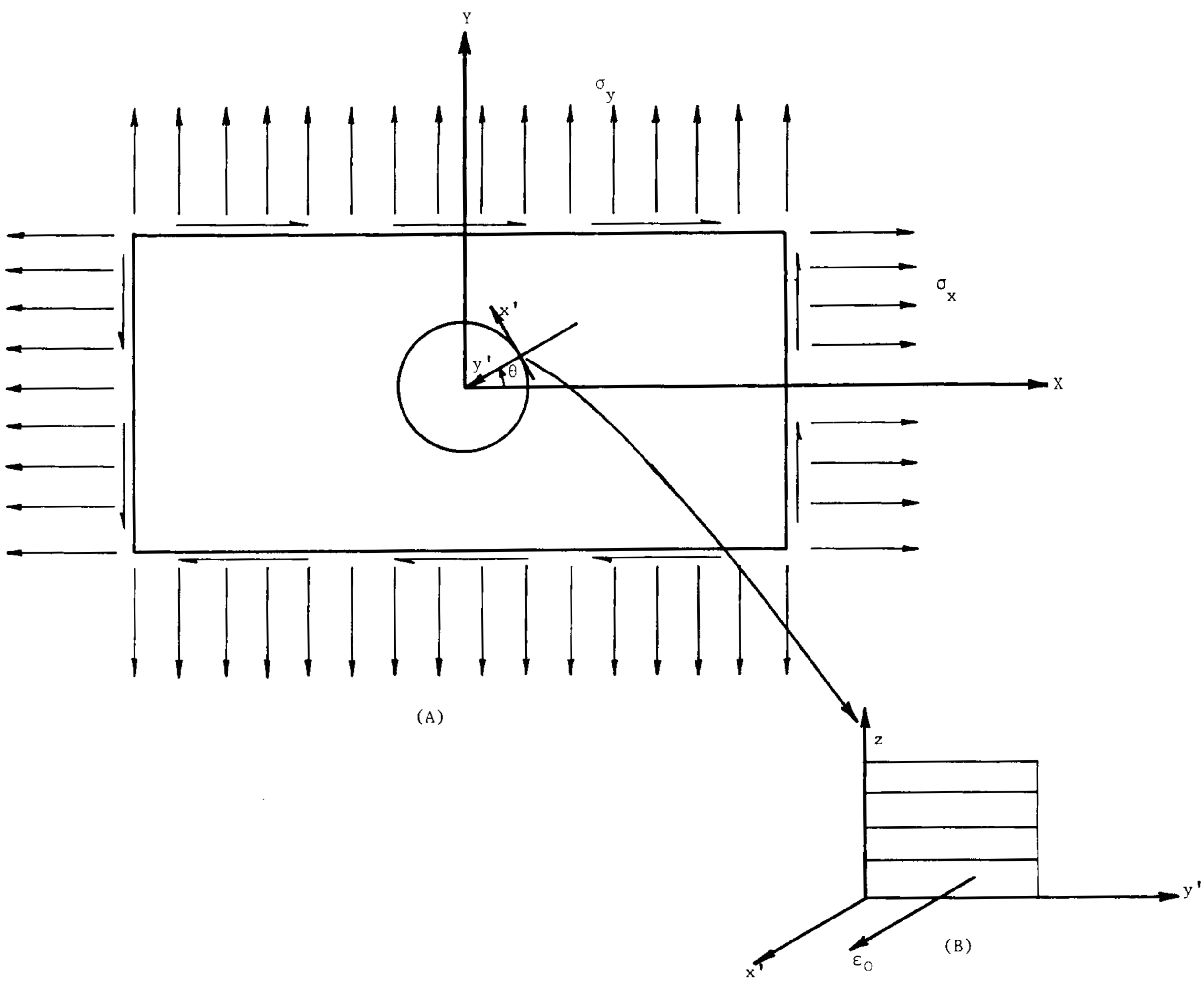

Figure 1

PROCEDURE

The analysis procedure is summerized in the following figure. The combination of closed-form (CFH - closed-form, hole [1] and CHI - closed-form, inclusion [2]) and FEM [3] solutions provide efficiency and economy in the interpretation of results.

Note: CLT is a Classical Laminate Plate Theory Algorithm

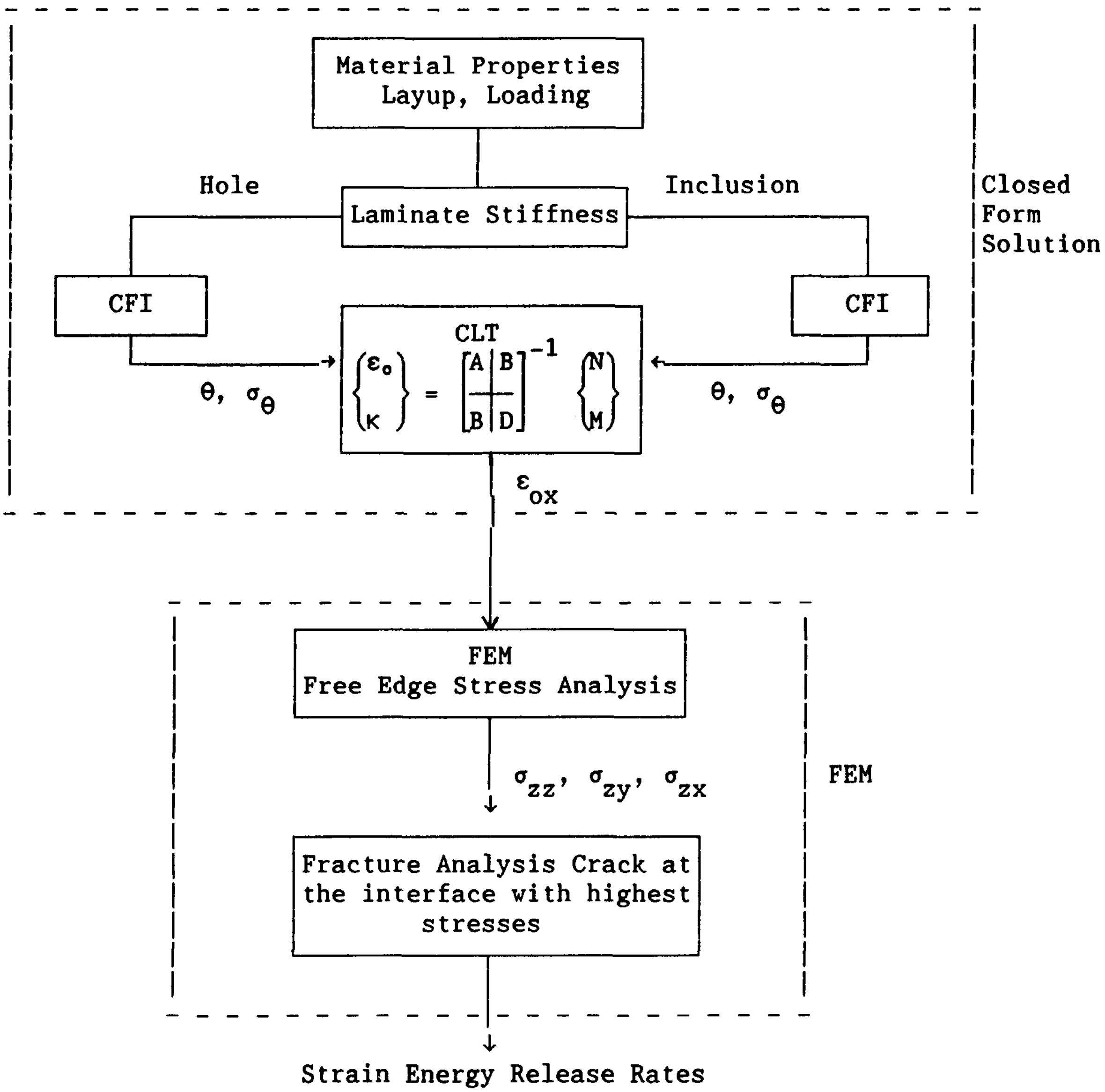

Figure 2.

INPLANE STRAIN/STRESS RESULTS

$[\pm 35/0/90]_s$ laminate is subjected to 5000 psi axial stress. The response of this laminate with a hole and with inclusions are tabulated below. The tangential stress is obtained from the closed-form solution and the strain is evaluated from CLT.

	E inclusion/ E plate	$\sigma_\theta / \sigma_{applied}$	ε_o
hole (w/o inclusion)	0	3.280	1710$\mu\varepsilon$
with soft inclusion (epoxy)	.169	1.865	972$\mu\varepsilon$
with rigid inclusion (steel)	3.128	.724	377$\mu\varepsilon$

Figure 3

TANGENTIAL STRESS AROUND THE HOLE BOUNDARY

The tangential stress field for a laminate with a hole subjected to uniaxial tension and shear is presented in Figure 4. These stresses are displayed as a function of θ around the boundary of the hole. As can be observed, the highest tangential stress is at θ = 90° for the tensile load and θ = 50.5° for the shear load.

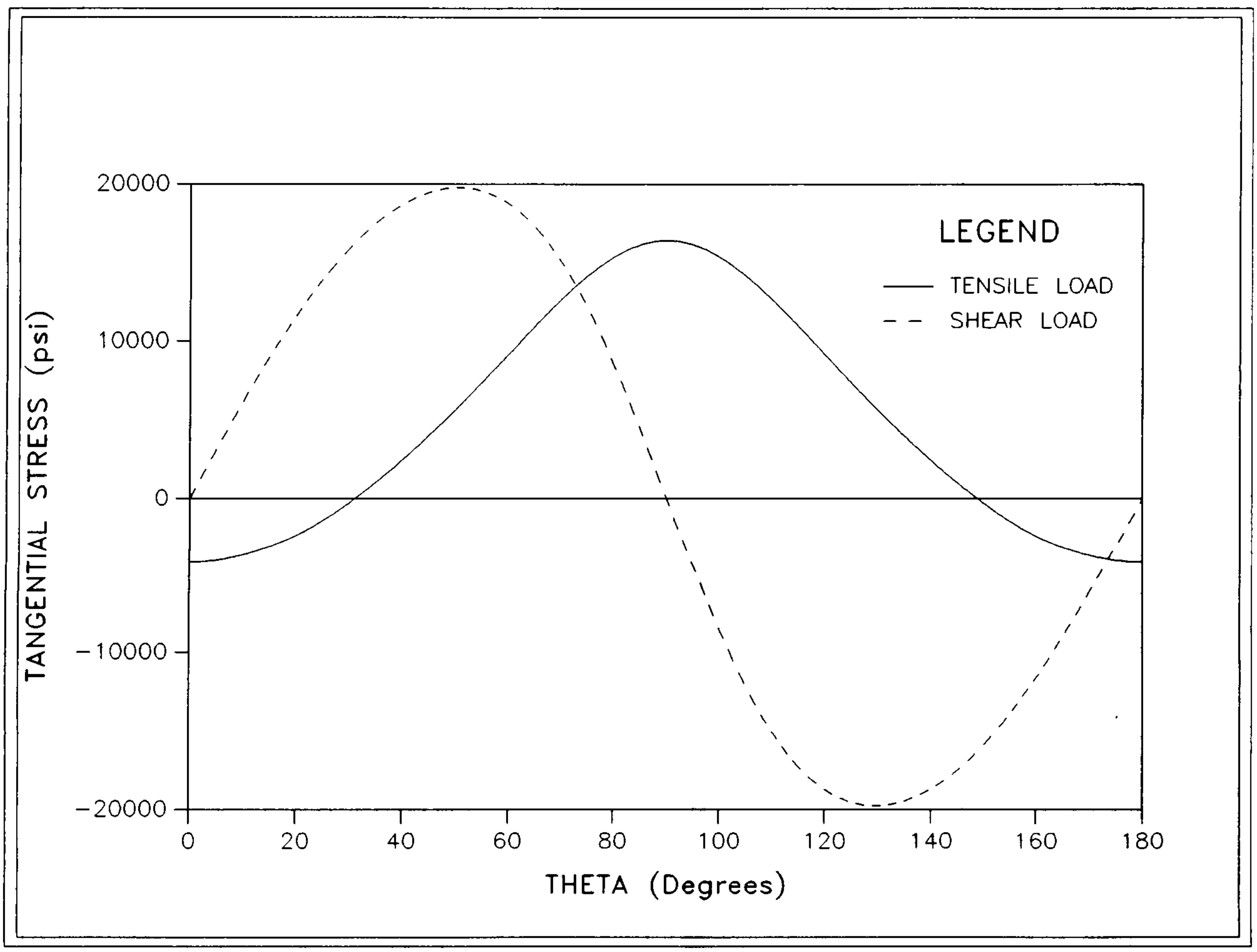

Figure 4

INTERLAMINAR NORMAL STRESS VARIATION

The closed-form reslults of Figure 4 are converted to applied tensile strain, $\varepsilon_{ox} = 1710\mu\varepsilon$ to be used in the FEM calculations. The FEM analysis models the laminate cross-section through-the-thickness and evaluates the interlaminar normal and shear stresses. Figure 5 presents the variation of the interlaminar normal stress along the y axis for each interface. Note that high stresses are at the free edge, between the 90/90 laminae and the 0/90 laminae.

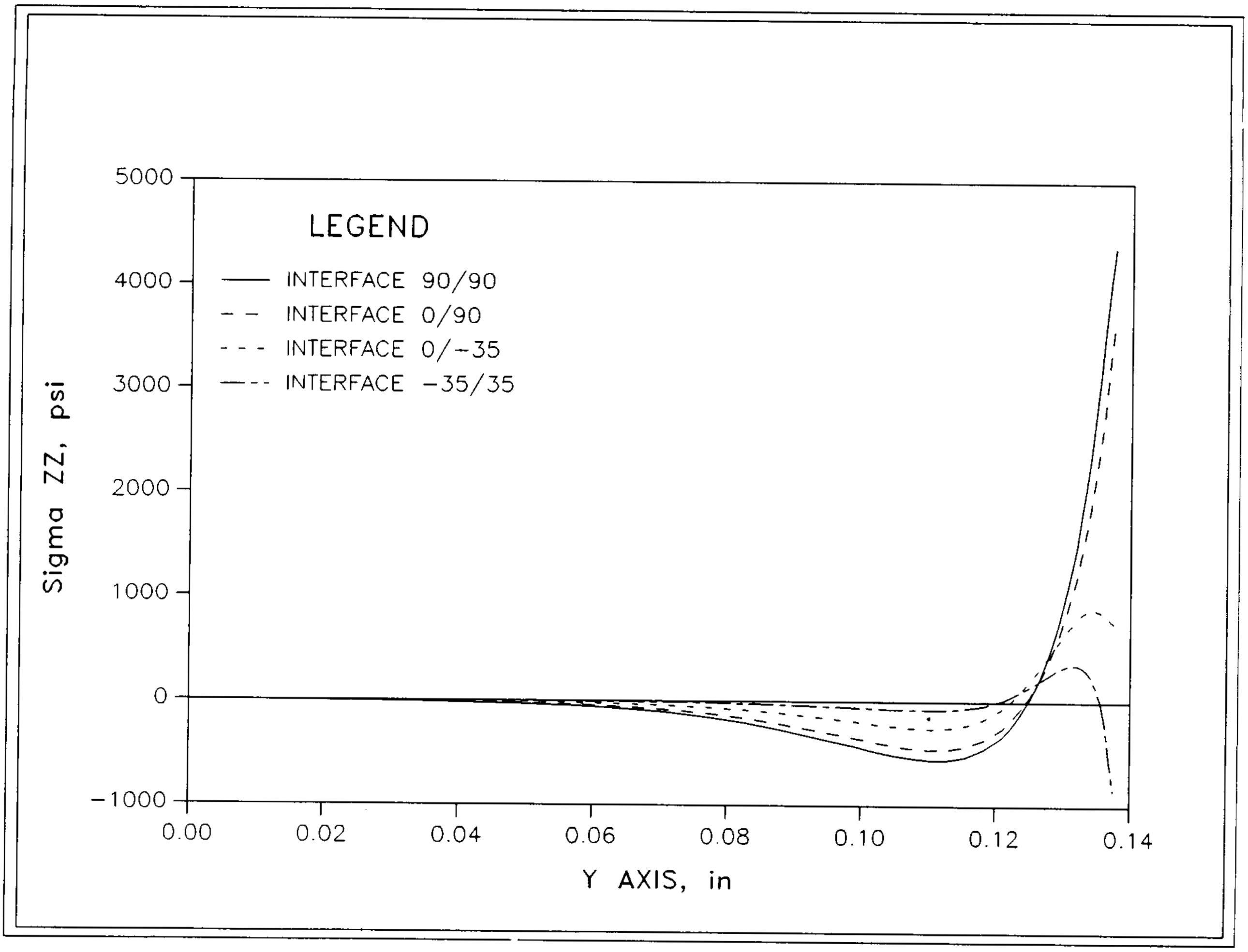

Figure 5

INTERLAMINAR SHEAR STRESSES

Figure 6 presents the variation of the interlaminar shear stresses, σ_{zx} and σ_{zy}, along the Y-axis for each interface. It should be observed that the highest σ_{zx} is at the free edge between the -35/35 laminae and that σ_{zx} rapidly vanishes inside the laminate. Note that the highest σ_{zy} is just inside the laminate near the free edge between the 0/-35 laminae.

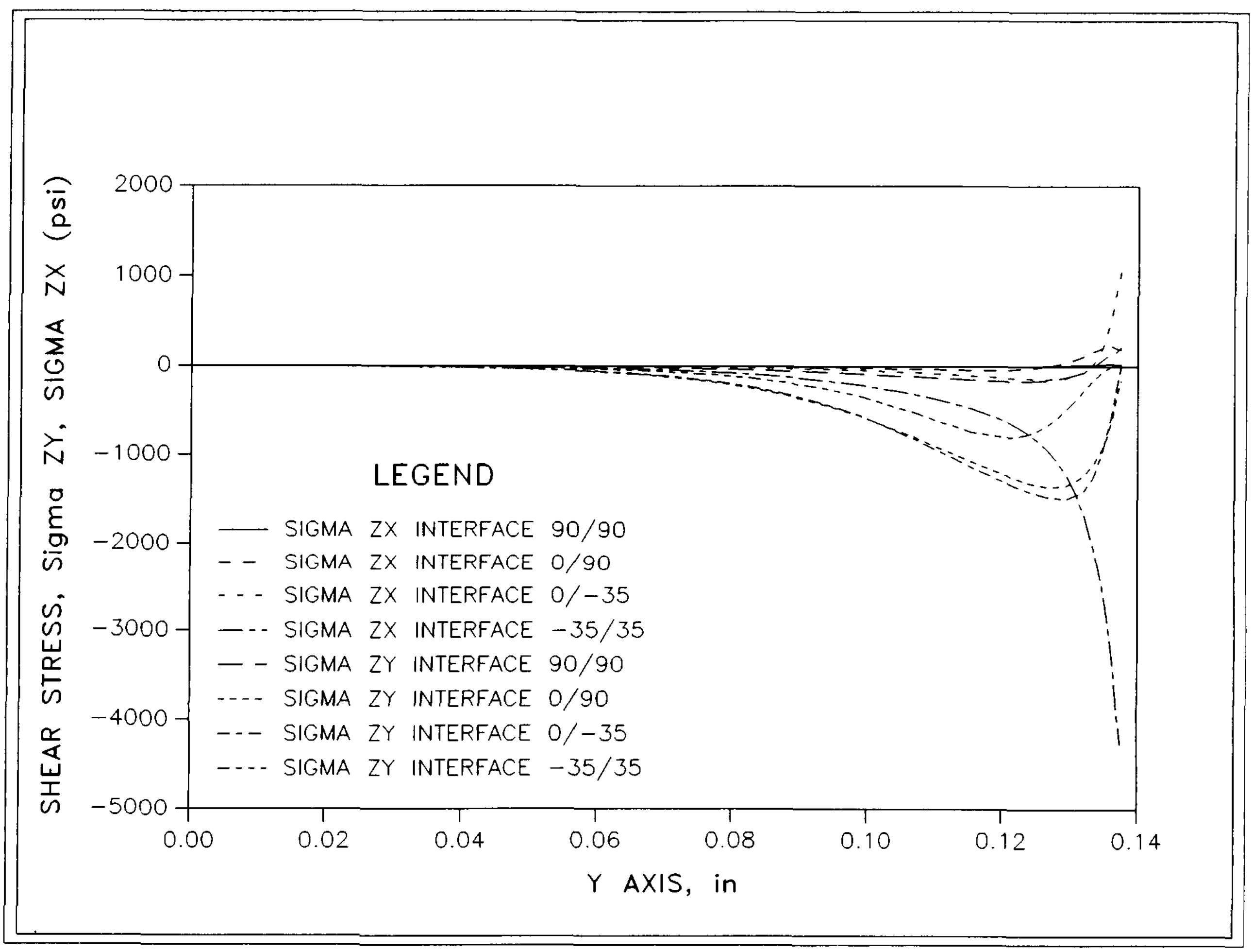

Figure 6

INTERLAMINAR STRESSES THROUGH THE THICKNESS

Figure 7 presents a comparison of the relative magnitudes of σ_{zz}, σ_{zx}, σ_{zy} at the free edge through the thickness. As can be observed, σ_{zy} is much smaller than σ_{zz} and σ_{zx}. σ_{zz} is relatively large at the midplane, 90/90, and at the first interface, 0/90. The shear stress σ_{zx} is highest at the third interface, -35/35. The fourth interface is the top surface of the laminate and has no interlaminar stresses.

The strain energy release rates for this laminate are evaluated by modeling a crack of a length equal to the thickness of 8 plies at the 0/90 interface. The resulting ratios are $G_I/_{GTOT}$ = .94096 and $G_{II}/_{GTOT}$ = .05827, indicating that Mode I behavior is dominant.

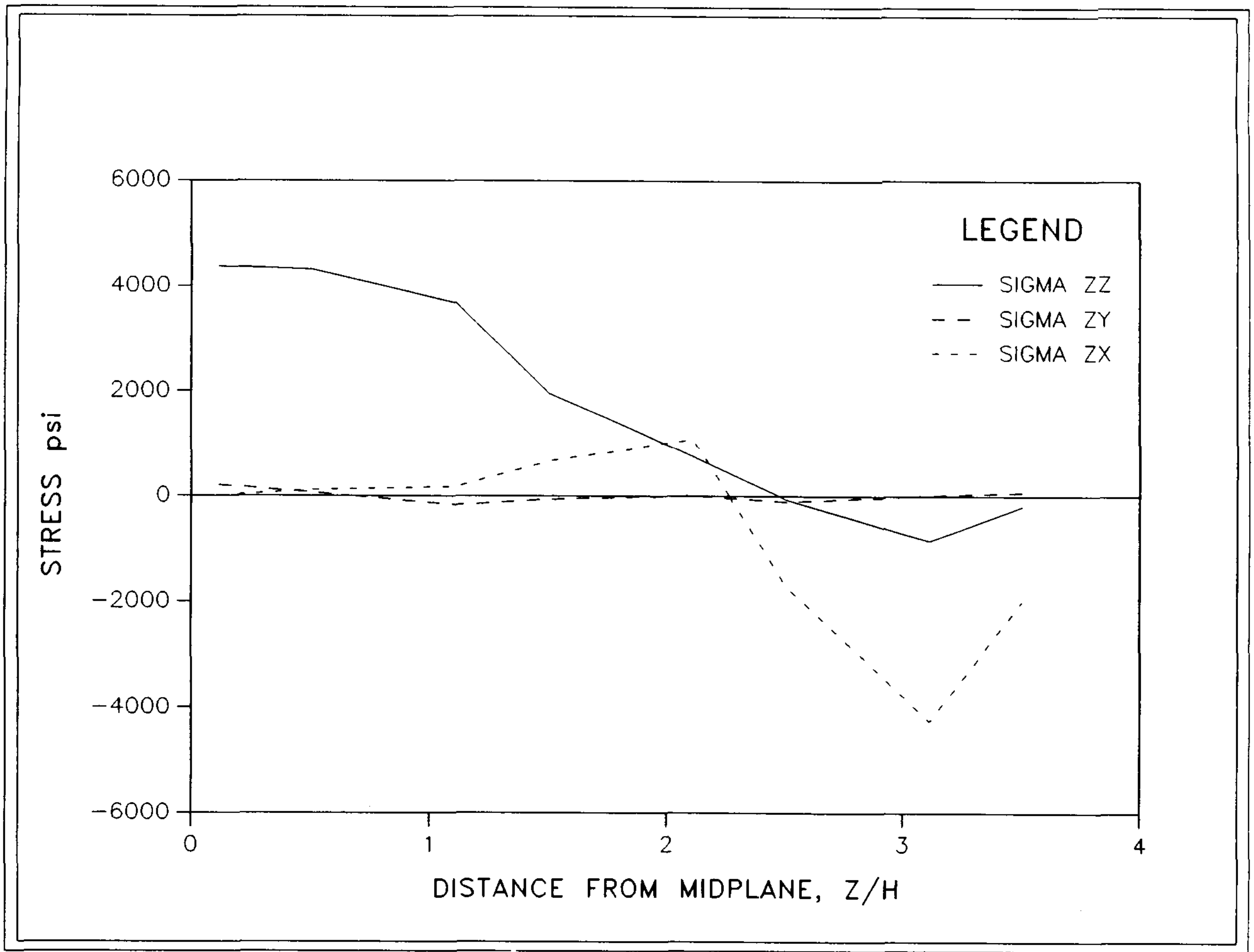

Figure 7

DEFORMATION OF HOLE/INCLUSION BOUNDARY

The effects of inclusion moduli on deformation are displayed in Figure 8. As expected a soft inclusion results in larger displacements. The $[\pm 35/0/90]_s$ laminate is loaded with uniaxial tensile stress of 50 ksi. The inclusion diameter is .5 inches.

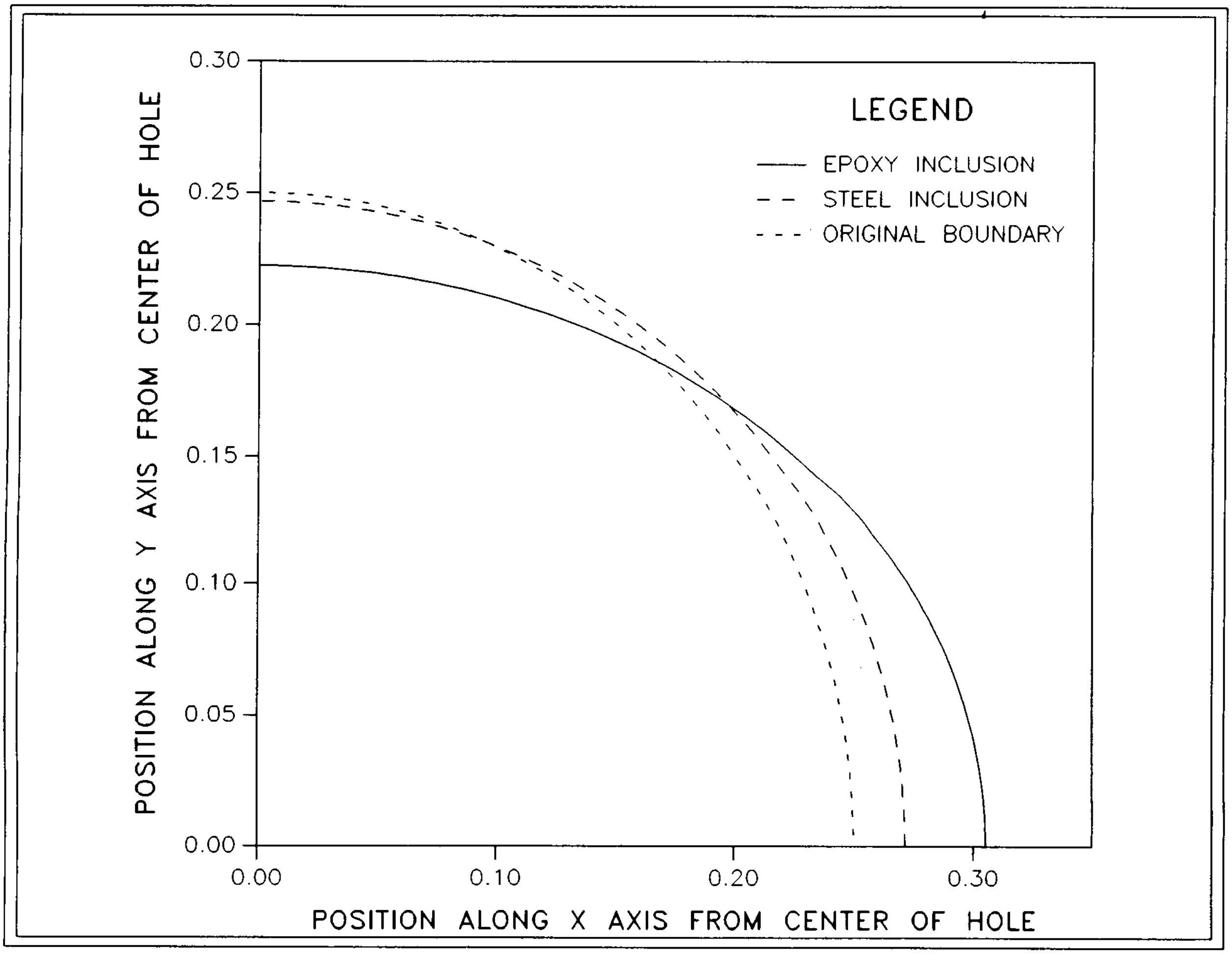

Figure 8

REFERENCES

1. S.C. Tan, "Composite Laminates Containing an Elliptical Opening," J. of Composite Materials.

2. S.G. Lekhnitskii, Anisotropic Plates, pp.190-218.

3. W.S. Chan and O.O. Ochoa, "Suppression of Edge Delamination In Composite Laminates By Terminating a Critical Ply Near the Edges," presented at the AIAA 29th SDM Conference, 1988.